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Research Article

The 50-year history of anglers' record catches of genus *Carassius*: circumstantial evidence of wiping out the native species by invasive conspecific

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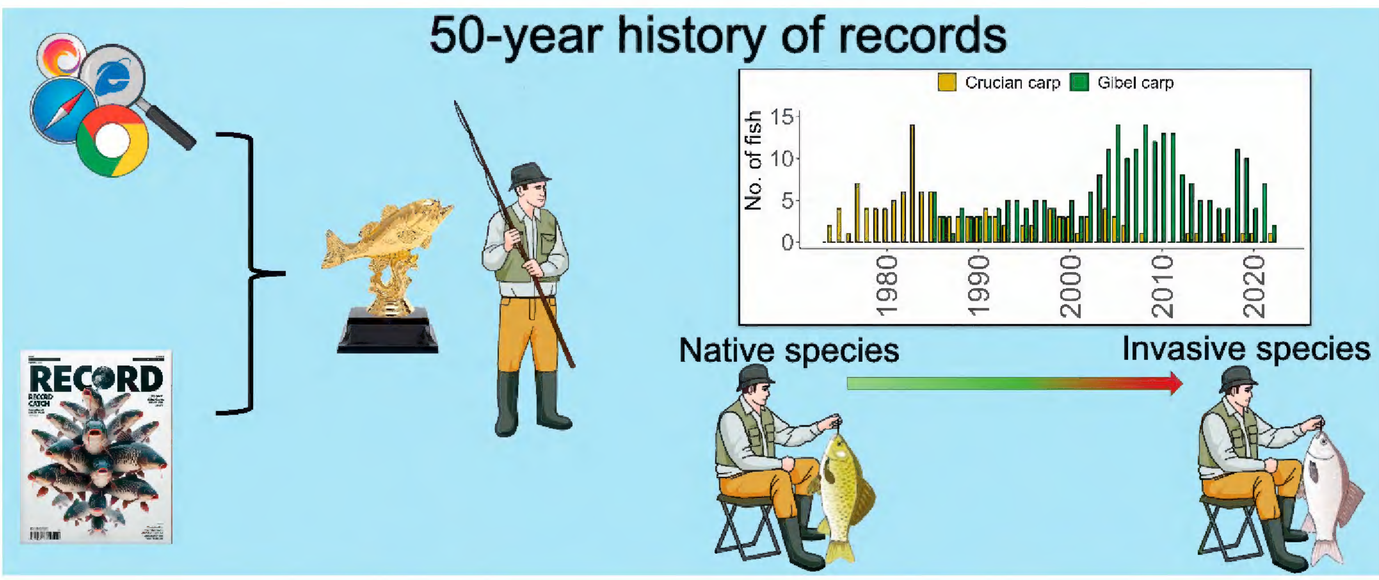
Abstract

Successful invasive non-native fish species can cause enormous damage to native biodiversity. In mainland Europe, the introduction of the gibel carp (*Carassius gibelio*) has led to a decline in populations of the formerly widespread native crucian carp (*C. carassius*). Both invasive and native species develop two phenotypes, namely stunted and deep-bodied, which depend on the intensity of competition and predation in the water body. The deep-bodied phenotype is associated with a more diverse fish community composition, can attain large sizes and is very attractive to recreational anglers. This study analysed trends in the record sizes of native crucian carp and invasive gibel carp (individuals close to the maximum attainable size of the species) reported by recreational anglers over the last 50 years in Czechia, recording the invasion of gibel carp from its beginnings to the fully established population phase. The study provides circumstantial evidence that gibel carp is behind transition from the relative abundance of large crucian carp to near extirpation, while large gibel carp have taken over the reports of record catches in the genus *Carassius*. This indicates that the crucian carp, which is currently classified as critically endangered in the Red List of Czechia, has very limited possibilities to realise its deep-bodied phenotype. It also shows the potential of using data from recreational anglers for mapping invasion processes and as a source of relatively localised information on endangered species.

Graphical abstract



Key words: Aquatic conservation, culturomics, crucian carp, gibel carp, iEcology, Prussian carp

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Introduction

Invasive non-native species can have an enormous impact on freshwater ecosystems, displacing native species or even causing their complete extinction (Gurevitch and Padilla 2004; van der Veer and Nentwig 2015; Šmejkal et al. 2023). Invasive non-native species can threaten native species through predation (Grabowska et al. 2019), competition for food resources and space in the ecosystem (Tapkir et al. 2022), hybridisation (Papoušek et al. 2008) or through disease transmission (Gozlan et al. 2005). The spread of invasive non-native species has been facilitated by intentional or unintentional introductions (Sakai et al. 2001; Blackburn et al. 2011; Almena et al. 2023) and one of the most common routes of introduction for invasive non-native species fish has been through aquaculture and the ornamental fish trade (Naylor et al. 2001; Balon 2004).

Fish of the Cyprinidae family were the first to be spread outside their native waters (Balon 2004). The gibel carp (*Carassius gibelio*) was accidentally introduced to Eastern Europe in the mid-20th century along with other cyprinids from the Amur Basin to be bred in aquaculture (Hensel 1971; Kalous et al. 2012). The migration of the invasive gibel carp in the Danube River was recorded in the 1970s (Tóth 1976) and the first records in Czechia date back to 1975–1976 (Halačka et al. 2003). The gibel carp rapidly invaded most of Western Europe and today reaches as far as the Scandinavian and Iberian Peninsulas (Wouters et al. 2012; Rylková et al. 2013; Ribeiro et al. 2015). The invasion went unnoticed to a certain extent due to the relatively high morphological similarity with the feral form of the goldfish (*Carassius auratus*) already present in Europe (Hensel 1971; Szczerbowski 2002), so that the exact development of the invasion process and the resulting damage to local aquatic ecosystems were not recorded in detail.

Due to limited resources in monitoring the progress of invasive non-native species, it has proven useful to utilise knowledge, photos and video recordings collected by people through approaches such as citizen science, culturomics and iEcology (Ladle et al. 2016; Jarić et al. 2020a, 2021). In addition, meaningful data can be collected by recreational anglers and managed by angling associations (Pinder et al. 2015; Venturelli et al. 2017; Pentyliuk et al. 2023, which, if collected systematically, can provide relatively standardised evidence of the progress of the species' invasion (Vejřík et al. 2019; Lyach 2022; Thomas et al. 2023). In addition, recreational anglers have a particular preference for the individuals of fish that are exceptionally large for the species in question (Wilde and Pope 2004; García-Asorey et al. 2011). These are referred to as "record" or "trophy" catches and are often presented in social media and angling magazines. These exceptional catches have not been particularly recognised by the scientific community in the past (Boon et al. 2024). However, they can be used to examine the status of the population in a particular area (Jarić et al. 2020b) and a decreasing size of catches and maximum length reached in the population can be indicative of overfishing or overall poor population status (Rochet and Trenkel 2003; Shin et al. 2005; Boon et al. 2024).

Despite the great attention paid by recreational anglers to large species and individuals (Beardmore et al. 2015; Birdsong et al. 2021), so-called "coarse fish species" also participate in record catch competitions, especially in countries with a large recreational angling community (Rolfe 2010; Locker 2014). One of these coarse fish species is the crucian carp (*Carassius carassius*), a cyprinid species that has the extraordinary ability to adapt its morphological characteristics to the expe-

rienced level of competition and predation (Brönmark and Miner 1992; de Meo et al. 2021, 2022). This adaptation is so extreme that the two phenotypes produced by crucian carp were previously considered to be two different species (Holopainen et al. 1997). In small water bodies, where competition for food is the main driver, a stunted form develops with a usual maximum size of less than 20 cm and an enlarged head compared to the total body size (Holopainen et al. 1997), while in the presence of piscivorous fish, the crucian carp changes its shape to a deep-bodied morph with a relatively small head and can reach a total length of up to 50 cm (Brönmark and Miner 1992; de Meo et al. 2021; Vinterstare et al. 2023). The latter form is prized by recreational anglers for its relative rarity and is, therefore, likely to be entered in record catches.

The crucian carp used to be one of the most abundant species in small European lentic waters; however, it declined due to habitat reduction and the invasion of the gibel carp in Western and Central Europe (Tapkir et al. 2022, 2023; Fedorčák et al. 2023) and due to competition with congener goldfish and common carp (*Cyprinus carpio*) (Copp et al. 2010; Busst and Britton 2015, 2017), as well as due to changes in pond management (Sayer et al. 2011, 2020). The crucian carp, gibel carp and feral goldfish are relatively similar, but the distinguishing characteristics between the crucian carp and the two invasive *Carassius* species allow the crucian carp to be recognised (Szczerbowski 2002; Papoušek et al. 2008).

This study thus attempts to retrospectively map the disappearance of the large-sized crucian carp after the invasion of the gibel carp, which was not well documented by the regular monitoring activities of scientists and nature conservation authorities. To this end, recreational angling magazines and websites dedicated to record catches were scrutinised for focal species. In addition to information on fish and catches, recreational anglers also provided photos of their record catches. The study selected evidence of record catches of native crucian carp and invasive gibel carp and used common bream (*Abramis brama*) and roach (*Rutilus rutilus*) as a reference dataset. These species were not as severely affected by the invasion of the gibel carp in Czechia as native species in southern latitudes and the gibel carp did not cause a significant decline in the populations of these species in reservoirs and large rivers (Říha et al. 2009; Lusk et al. 2010; Perdikaris et al. 2012). It was hypothesised that: i) the increase of the invasive gibel carp will be accompanied by a decline in reports of large individuals of the native crucian carp over time and ii) the reference datasets of common bream and roach will not show the same trends as those of native crucian carp due to the lower impact of the gibel carp invasion on these species.

Materials and methods

Record catches extraction and verification

The first dataset compiled for the study includes reported catch records of the focal species for which the recreational angling magazines “Rybářství”, “Rybář”, “Český Rybář”, “Sportovní Rybářství”, “Kajman” and the recreational angler´s website “mrk.cz” were examined for evidence of record fish of the species crucian carp, gibel carp, common bream and roach from the years 1973–2022, resulting in a dataset spanning 50 years. The submitted photos, together with the total length (TL, in cm), weight (kg; W) and angling area code, were first reviewed by a mag-

azine editor-in-chief or an expert (an experienced angler and often an authority from the Czech or Moravian Anglers Union, or from the anglers' community on the mrk.cz website) before being officially admitted to the competition. Selected photos appeared directly in the magazines, while the rest of the record catches were not selected for publication in the magazines and were included in the annual summarised statistics of record catches. Both datasets were extracted in a standardised manner, focusing on the presence of TL, W, species, water type (lentic, lotic) and numerical angling area identifier (code unique to a particular water body or river section, if available in the record). In addition, due to the similarity between crucian carp and gibel carp, the authors' team reviewed all available photos to assess the reliability of the dataset and changed the category from crucian carp to gibel carp (or vice versa) where appropriate. We also extracted the central GPS position of the angling site and the total area in ha and assigned the angling ground to three existing watersheds in Czechia (Elbe, Danube and Odra; Suppl. material 1).

The angling sites are part of the Czech and Moravian Anglers Unions, which are large organisations with around 330,000 members and whose angling grounds cover the catchment areas of the Elbe, Danube (Morava) and Odra Rivers in Czechia. There are 76,000 kilometres of watercourses and 107 reservoirs in Czechia. The area of waters totals 42,000 hectares, both in lotic and lentic ecosystems and is accessible for recreational angling with a licence.

Statistical analyses

To estimate whether the number of record-sized individuals of a given species follows any pattern in the time series, the data were tested with the funtimes package (Lyubchich and Gel 2023) using the local regression-based WAVK test method (Wang et al. 2008; Lyubchich et al. 2013) within the R software (R Core Team 2023). The Sieve bootstrap enhancement to test for a trend (monotonic or non-monotonic) was used with the WAVK function for each species separately (Lyubchich et al. 2013).

In addition, the records of native crucian carp and invasive gibel carp were analysed to determine whether they differ in their maximum recorded length and weight. The crucian carp and gibel carp datasets were tested for normality assumptions using the Shapiro-Wilk normality test. As the data were not normally distributed, the Mann-Whitney U-test was used for all data regardless of the year of capture.

Generalised additive models (GAM) were used to assess trends in fish size during the study period (Wood 2017). To test whether the trend in maximum length and weight changed over the years, two GAMs were created with all species in the first stage, with length and weight as response variables and species, year and angling ground size as explanatory variables. To check the validity of k-value, the gam.check function was used (Augustin et al. 2012; Wood 2017). In addition, a total of eight GAMs were created (for each species separately) with length and weight as response variables and year as an independent variable to assess species-specific trends over the years. The effect of the variable year was modelled using cubic regression splines (bs = "cr"). General additive models were created using the mgcv package (Wood 2001, 2017).

Generalised additive models were used to plot the points of records of all four species for each decade, using the number of reported catches in each period as the response variable and their GPS locations as the explanatory variable, by creating

contour plots (Wood 2017). Each line (or contour) represents the number of reported catches in that area within the country. The proximity of the lines indicates the steepness of the gradient. The model check was performed using the gam.check function (Augustin et al. 2012; Wood 2017). The graphical visualisation of the data was created using the ggplot2 and ggmap packages (Kahle and Wickham 2013; Wickham 2016).

Results

In total, the dataset contained 982 records in the period 1973–2022, with 124 records of native crucian carp (mean TL = 39.8 ± 4.3 cm, mean W = 1.46 ± 0.43 kg), 248 invasive gibel carp (TL = 44.5 ± 4.0 cm; W = 1.82 ± 0.50 kg), 369 common bream (TL = 62.3 ± 5.7 cm, W = 3.29 ± 0.87 kg) and 241 roach (TL = 40.8 ± 3.5 cm, W = 1.09 ± 0.27 kg). Of the total number of catches, 66.9% of the native crucian carp were caught in lentic waters, while the figures for invasive gibel carp, common bream and roach were 62.9%, 42.5% and 36.5%, respectively. The highest contribution to the dataset was made by the magazine "Rybářství"(700), followed by Kajman (103), mrk.cz (93), Český Rybář (48), Rybář (34) and Sportovní Rybářství (4). When checking the available photos of crucian carp and gibel carp, 27 and 98 photos were obtained, respectively. The reliability of species identification on these photos reached 63% for crucian carp and 100% for gibel carp. All misidentifications were made after 1993, while all 10 crucian carp records with photos were confirmed as crucian carp before that year.

Trend analyses of reported record fishes

The test for any trend on all four species indicated that all species contain a significant trend in their data (WAVK test: crucian carp $p < 0.001$; gibel carp $p < 0.001$; common bream < 0.001; roach < 0.05). Trends in number of record crucian carp reported by recreational anglers declined sharply after 2005 and, for these data and the best fit, we used a model with moving window (MW) 7 and a polynomial fit of degree 11 (WAVK test = 34.098, $p < 0.001$). Reports of invasive gibel carp first appeared in 1985 and were comparable in number to native crucian carp between 1985 and 2000. Since then, reports of invasive gibel carp have become very dominant in terms of record sizes (Fig. 1A). The best fit for the gibel carp was a linear increasing trend (WAVK test = 152.51, MW = 7, $p < 0.001$). In comparison to this trend, the record size reports for common bream and roach did not show a strong decreasing or increasing trend (Fig. 1B, C). The best fits were a polynomial fit of degree 3 in common bream (WAVK test = 35.996, MW = 9, $p < 0.001$) and a linear trend in roach (WAVK test = 40.395, MW = 9, $p = 0.021$).

Trends in species maximum sizes

The reported native crucian carp were, on average, smaller than invasive gibel carp in both length (39.8 ± 4.3 cm vs. 44.5 ± 4.0 cm, W = 6167.0, $p < 0.001$; Fig. 2A) and weight (1.46 ± 0.43 kg vs. 1.82 ± 0.50 kg, W = 8282.5, $p < 0.001$; Fig. 2B). The general additive model for maximum recorded length (M1) and weight (M2) differed significantly between fish species, with the exception of roach length (Table 1), with a positive estimate for gibel carp and common bream and a negative

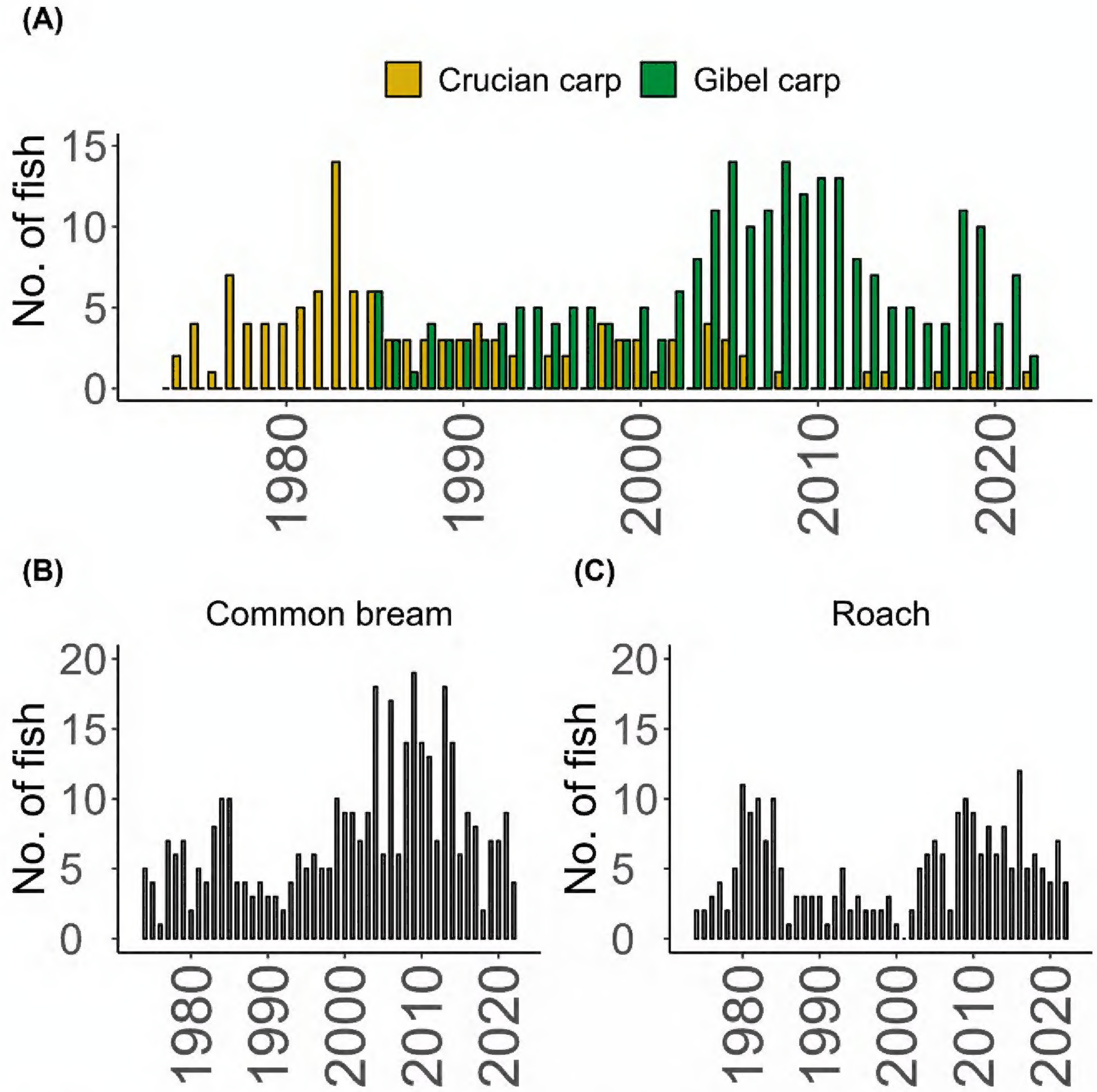

Figure 1. The number of record catches extracted from angling magazines and websites between 1973 and 2022 for **A** the native crucian carp (*Carassius carassius*), invasive gibel carp (*C. gibelio*) and reference fish species **B** common bream (*Abramis brama*) and **C** roach (*Rutilus rutilus*). The period captures the invasion phase of gibel carp from early invasion phase to fully established, as well as the current impact on the native and critically endangered crucian carp in Czechia.

estimate for roach in terms of weight and, further, with a positive effect of angling ground size (M1: $t = 2.36$, $p = 0.018$; M2: $t = 2.34$, $p = 0.020$) and a positive effect on weight in the Elbe catchment (M2: $t = 2.28$, $p = 0.023$). The effect of year was significant for both models (M1 $F = 4.844$, $p < 0.001$; M2: $F = 3.936$, $p < 0.001$) and the total explained deviation of the model was 83.4% and 71.8% for M1 and M2, respectively. The trend for the recorded maximum lengths was unimodal for native crucian carp with maximum values around the year 2000 (GAM: $F = 15.12$, $p < 0.001$, 33.4% deviance explained), while it gradually increased for invasive gibel carp (GAM: $F = 18.84$, $p < 0.001$, 24.1%), was relatively stable for common bream (GAM: $F = 0.009$, $p > 0.05$, 0.0%) and showed a fluctuating trend with the maximum around 1990 in roach (GAM: $F = 3.841$, $p < 0.001$, 14.7%; Fig. 3). Similarly, the maximum weight was recorded around the year 2000 for crucian carp (GAM: $F = 21.93$, $p < 0.001$, 44.7%), while the maximum recorded weight increased gradually in gibel carp (GAM: $F = 3.726$, $p = 0.002$, 8.5%) and the fit was linear in common bream (GAM: $F = 2.335$, $p = 0.014$, 7.6%) and fluctuating in roach (GAM: $F = 10.19$, $p < 0.001$, 16.7%; Fig. 4).

The GAM contour plots showed the concentration of large-sized fish mainly in the area of the lowland rivers and the interconnected oxbows. While common bream and gibel carp were almost ubiquitous, record-sized crucian carp and roach showed a more aggregated distribution with few hotspots in Czechia (Fig. 5).

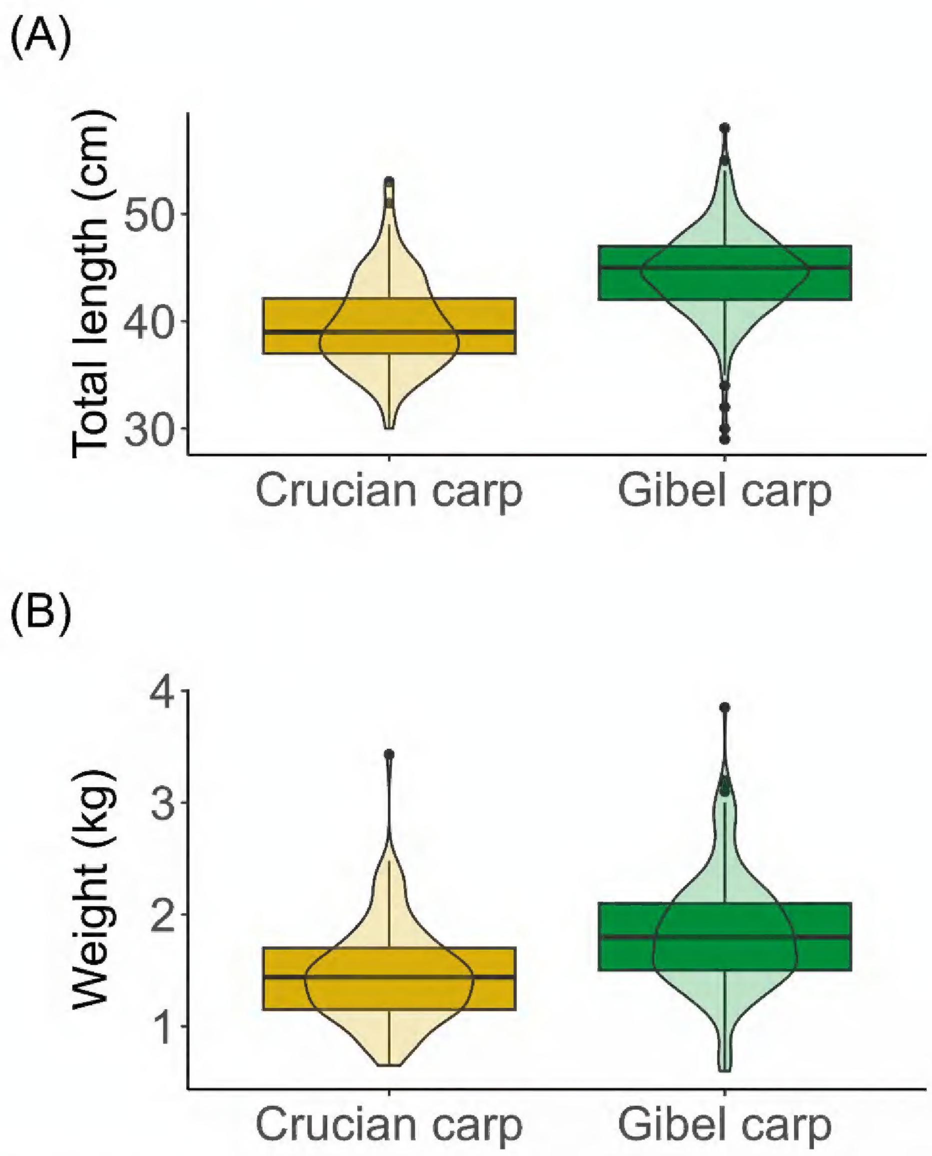

Figure 2. The comparison of reported record catches size in the 50-year dataset. The maximum attainable size of the invasive gibel carp (*Carassius gibelio*) significantly exceeds the maximum size of the native crucian carp (*C. carassius*) in Czechia in both **A** total length and **B** weight. The boxplot boundaries represent upper and lower quartiles; the thick lines represent medians and the whiskers represent 1.5 times the interquartile range. Violin plots represent kernel density distribution.

Table 1. The parametric coefficient of general additive models for record catches of native crucian carp (*Carassius carassius*), invasive gibel carp (*C. gibelio*), common bream (*Abramis brama*) and roach (*Rutilus rutilus*) with response variable of total length (upper table) and weight (lower table). The significance of smooth term on variable year was < 0.001 for both models and explained deviance was 83.4 and 71.8%, respectively.

	Estimate	*t*-value	*p*-value
GAM Length			
Intercept	40.174	74.966	<0.001
Species:Roach	0.383	0.709	NS
Species:Bream	22.069	43.021	<0.001
Species:Gibel	3.812	6.876	<0.001
Angling ground size	0.001	2.369	0.0181
Type: Lotic	-0.088	-0.267	NS
Basin: Elbe	0.298	0.840	NS
Basin: Odra	-0.820	-1.152	NS
GAM Weight			
Intercept	1.408	19.973	<0.001
Species:Roach	-0.420	-5.908	<0.001
Species:Bream	1.810	26.838	<0.001
Species:Gibel	0.314	4.305	<0.001
Angling ground size	$7.094e^{-05}$	2.157	0.031
Type: Lotic	0.001	0.198	NS
Basin: Elbe	0.107	2.280	0.029
Basin: Odra	-0.041	-0.440	NS

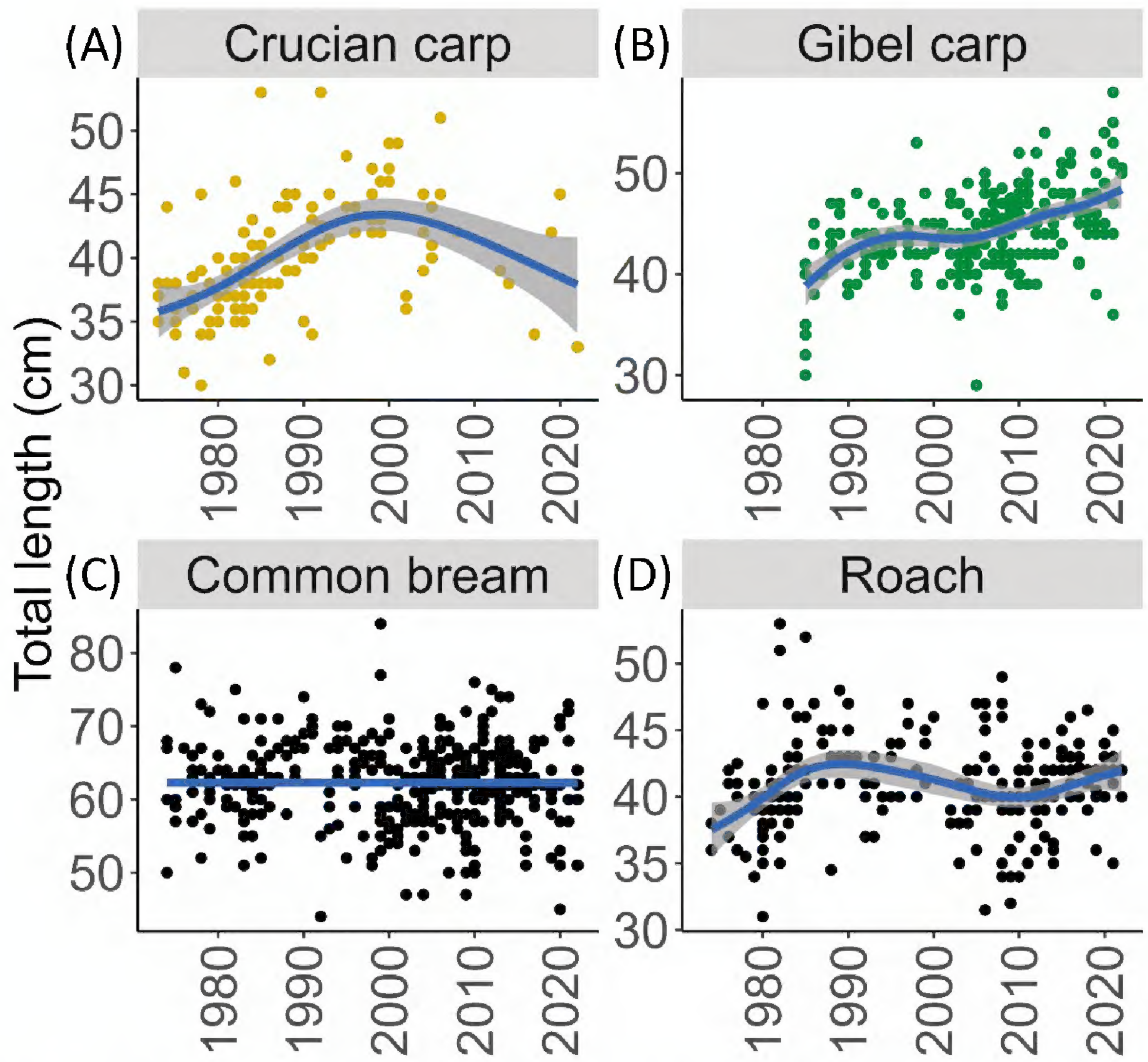

Figure 3. The GAM trend-line of record catches size (total length) in the 50-year dataset. The GAM fit has been computed with the stat_smooth function. The data suggest: **A** unimodal response in the native crucian carp (*Carassius carassius*) with time **B** increase maximum attainable size in the invasive gibel carp (*C. gibelio*) **C** stabilised size limits in common bream (*Abramis brama*) and **D** maximum in 1990 in roach (*Rutilus rutilus*).

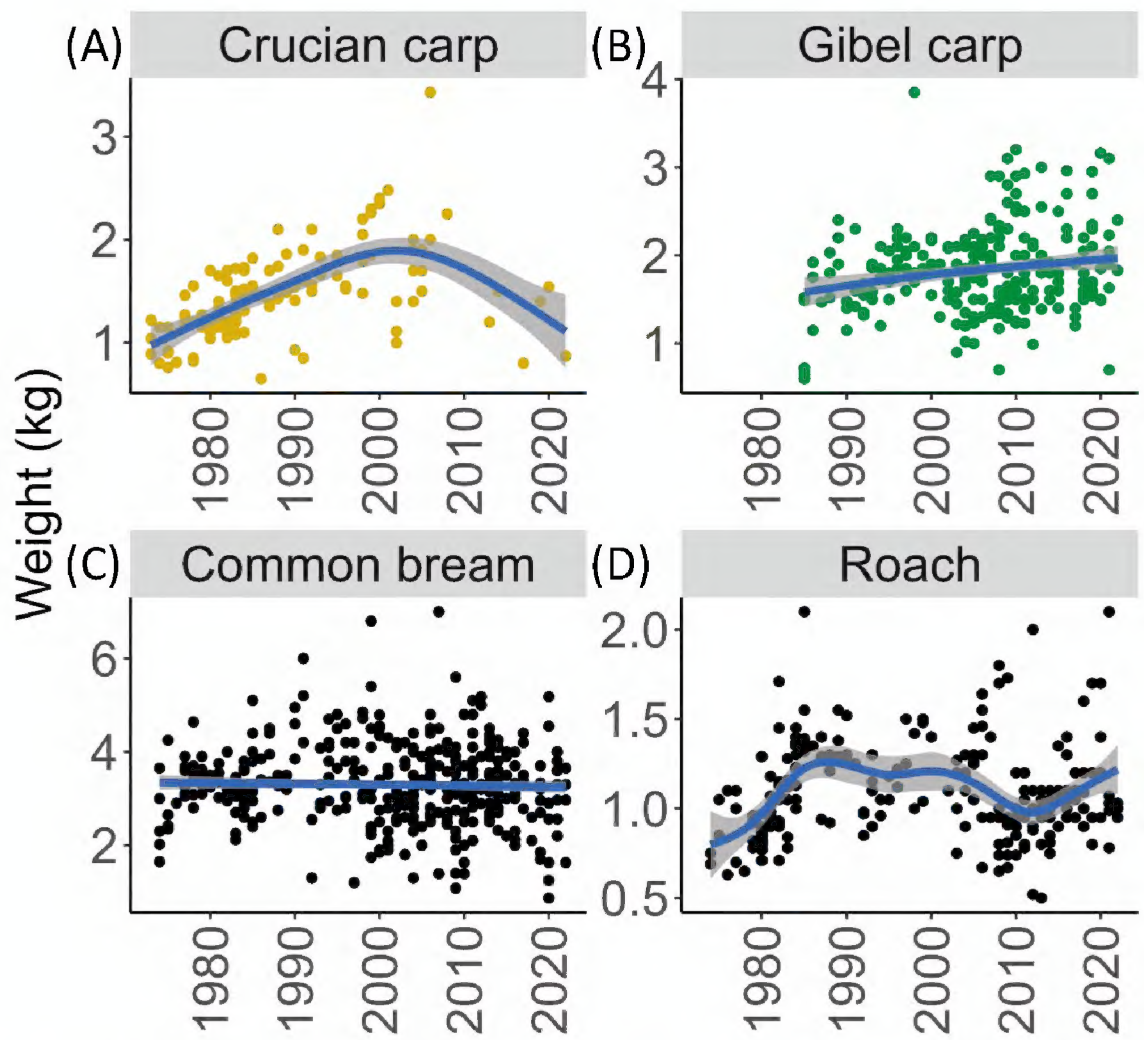

Figure 4. The GAM trend-line of record catches size (weight) in the 50-year dataset. The fit has been computed with the smooth function with a value of k = 1 to avoid overfitting. The data suggest **A** unimodal response in the native crucian carp (*Carassius carassius*) with time **B** moderate increase in maximum attainable size in the invasive gibel carp (*C. gibelio*) **C** relatively stabilised size limits in common bream (*Abramis brama*) and **D** fluctuating trend in roach (*Rutilus rutilus*).

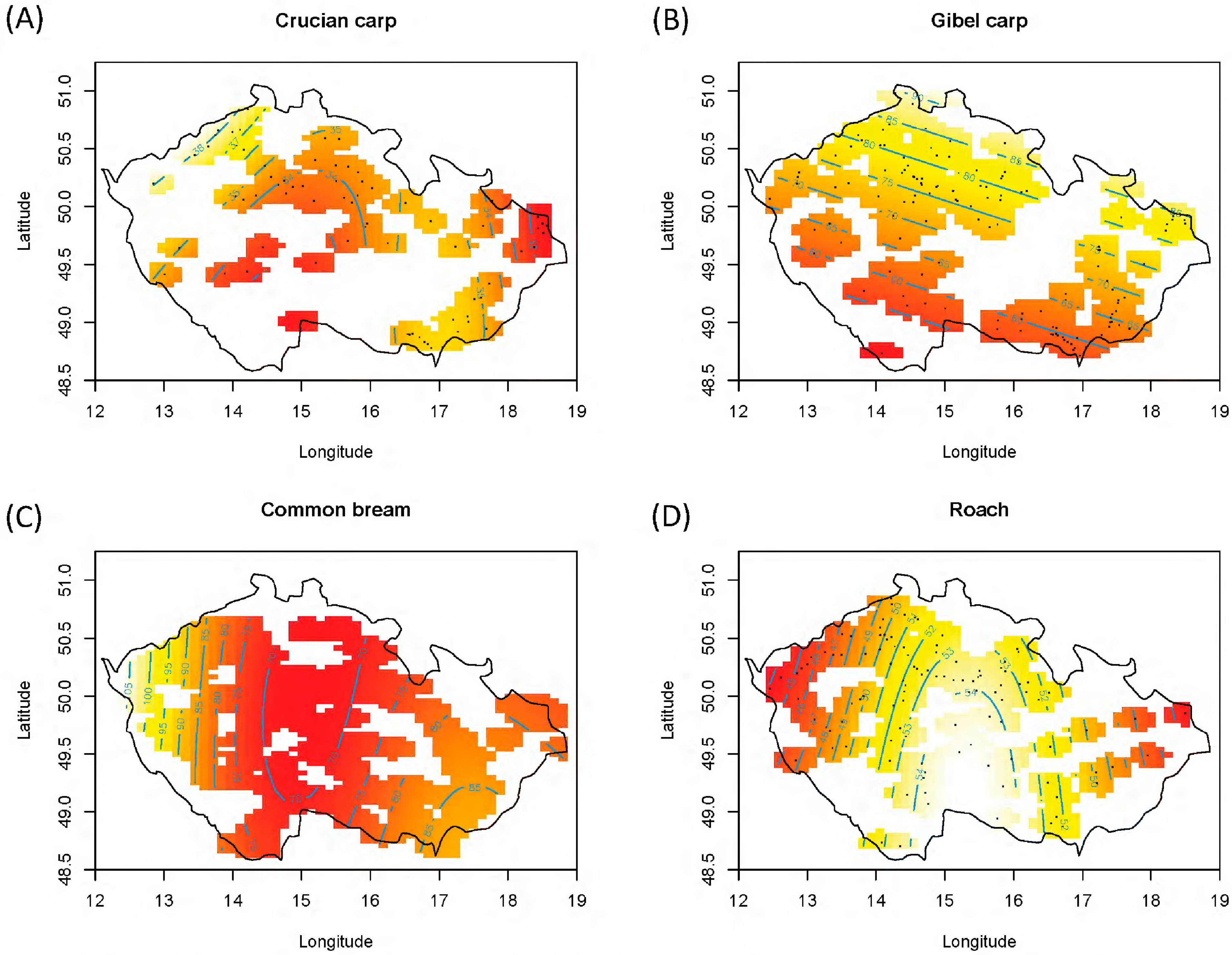

Figure 5. Contour plots based on GAMs for **A** native crucian carp (*Carassius carassius*) **B** invasive gibel carp (*C. gibelio*) **C** common bream (*Abramis brama*) and **D** roach (*Rutilus rutilus*) for all study period, where the number of reported record catches in a given area was used as the response variable and their GPS locations as the explanatory variable. Each line (or contour) represents the reported catches in that region within the country. The proximity of the lines indicates the steepness of the gradient. Colours show the abundance of records with red indicating the highest abundance.

Discussion

Given the speed at which invasions are progressing in the aquatic environment, it appears that utilising the information collected from citizens can help combat the problem (Jarić et al. 2020b, 2021; Löki et al. 2023). This study shows circumstantial evidence of declining trend in the distribution of the native large crucian carp in Czechia, as recorded by recreational anglers´ catches. This trend in record catches of invasive gibel carp and native crucian carp corresponds well with the status of crucian carp in Czechia, where the first change in species status from "Least Concern" to "Vulnerable" occurred in 2000, i.e. around the same time that catches of gibel carp appeared more frequently in the record statistics than those of crucian carp. The increase in misidentifications in the native crucian carp records after 1993 indicates that the data are likely to include some misidentified gibel carp, so that their dominance in the catches will be likely even more absolute. However, this dataset did not contain all variables that could have accounted for the decline of crucian carp; thus, there is a chance that other biotic (e.g. more intense common carp stocking) or abiotic (e.g. climate change) factors contributed to its decline.

Trends in occurrence and size with relation to species ecology

Both native crucian carp and invasive gibel carp were found more frequently in the lentic waters, which is consistent with their ecology (Holopainen et al. 1997; Tarkan et al. 2023). The size of the angling water and the catchment area of the Elbe had a slight positive influence on fish size in the general model for all species. This result may need to be tested in more detail using a larger dataset, as not much scientific literature has been published on angling for fish of record size and such result may apply only to some species.

While the records of both reference species showed a relatively stable trend around the same average value, both native crucian carp and invasive gibel carp showed GAM trend-lines indicating changes in maximum size. For crucian carp, the unimodal response with a decline in recorded maximum size in recent years suggests either growth limitations or possible confusion with invasive gibel carp or hybrids between crucian carp and gibel carp around 2000. Both options are possible, as the growth restriction may be caused either by increased interspecific competition due to the invasion of the gibel carp (Auwerx et al. 2021; Tapkir et al. 2022) or by the negative effects of increasing average temperature on fish growth (Emmrich et al. 2014). While the prediction of crucian carp via growth parameters suggests that growth increases with temperature (Tarkan et al. 2016), the record-size crucian carp seems to benefit from rather low temperatures and the best lakes are located in northern latitudes and with the presence of piscivorous fish (Rolfe 2010; Vinterstare et al. 2023).

Hybridisation is also a likely explanation, as both species form hybrids under certain circumstances (Papoušek et al. 2008; Knytl et al. 2018) and hybrids also form between the crucian carp and the goldfish (Smartt 2007). Despite the emphasis on hybridisation in *Carassius* studies (Papoušek et al. 2008; Wouters et al. 2012; Knytl et al. 2018, 2022), the results of strong invasive gibel carp suggest that this is competition between native crucian carp and probably the main reason for the decline in crucian carp populations (Tapkir et al. 2022, 2023).

The sequence of gibel carp invasion in Czechia

The gibel carp was accidentally introduced to Hungary together with the commercial Asian fish species (*Hypophthalmichthys molitrix*, *H. nobilis*, *Ctenopharyngodon idella*) in the 1950s (Tóth 1976; Holčík 1980). The westward invasion of the gibel carp started in the Danube catchment, and commercial catches of *Carassius* genus increased from 3% to 15% in the period from 1958 to 1976 in the Danube (Tóth 1976; Holčík 1980) and the first records in Czechia were in the Morava River (Danube watershed) in 1975–1976 (Halačka et al. 2003). Due to inter-basin aquaculture transfers, the first reports of gibel carp in the Elbe River Basin were recorded as early as 1980 (Kubečka 1989) and soon became the dominant taxa within the genus *Carassius* (Halačka et al. 2003; Lusk et al. 2010). The first record in this dataset also comes from the Danube catchment. However, this study focused on fish of record size, so it is likely that several years will pass between the invasion and the record catches.

There are currently three invasive species of the genus *Carassius* living in Czechia, the goldfish (including feral form), *C. langsdorfii* in addition to already mentioned gibel carp (Kalous et al. 2007, 2013; Rylková et al. 2013). These species can hy-

bridise with each other and form viable populations of hybrid origin (Keszte et al. 2021) and are, therefore, considered a species complex in some studies (Rylková et al. 2013; Knytl et al. 2022). All of them are of similar appearance (Hensel 1971), the largest individuals can reach a length of more than 40 cm and, therefore, all can be included in angling statistics under the name of invasive gibel carp. Although it is widely believed that the gibel carp is the most widespread invasive *Carassius* species in Central Europe and the other two species are of lesser importance in terms of competition with native crucian carp (Lusk et al. 2010; Musil et al. 2010; Fedorčák et al. 2023), it might be interesting to investigate the relative proportion of these invasive species in European mainland.

Engaging public in conservation of crucian carp

The passion for enhancing native crucian carp populations was first brought to public attention in England, where Peter Rolfe launched his attempt as a pilot angler to reintroduce the species to Norfolk waters and promote the existence of exceptionally large fish in ponds (Copp and Sayer 2010; Rolfe 2010). The approach has been underpinned by the scientific literature and the presence of European pike (*Esox lucius*) has been embedded in the management of larger ponds to encourage the presence of the deep-bodied phenotype that can reach exceptional sizes that are attractive to recreational anglers (Brönmark and Miner 1992; Brönmark et al. 1995; Pettersson and Bronmark 1997; Rolfe 2010). This concept involves easing the intraspecific competition through predation (i.e. thinning out the carp population in the water body) and the simultaneous production of crucian carp in small ponds and stocking in larger water bodies.

Although the conservation and fisheries management described above is artificial, it has its roots in the life-history strategy of the crucian carp. In the floodplain rivers, the population has a metapopulation structure with a rare deep-bodied phenotype in multi-species community of large water bodies or lowland rivers (Brönmark and Miner 1992; Brönmark et al. 1995; Holopainen et al. 1997). These individuals can colonise pools in the floodplain and lay the foundation to the shallow-bodied phenotype that is formed in a single-species community without the presence of piscivores due to the frequent occurrence of anoxia (Blažka 1958; Holopainen and Hyvärinen 1985; Piironen and Holopainen 1986). These pools are then source populations and provide a surplus of fish in the main river channels during floods, where they can produce deep-bodied and potentially large-sized fish. From the perspective of Czechia, it appears that the deep-bodied phenotype disappeared faster than the shallow-bodied phenotype, as citizen-science projects resulted in finding few tens of sites (Šmejkal et al. 2021). Water Framework Directive monitoring in the Vltava watershed has not detected crucian carp in the last 15 years, while gibel carp are abundant (Bartoň and Šmejkal 2022), so we can assume that the trend presented in the catch records is reliable.

Culturomics role in fish conservation with emphasis on large-size fish

Culturomics in conservation has been shown to be an effective means of raising public understanding, framing conservation issues and engaging people in timely environmental monitoring (Ladle et al. 2016). Recreational angling with catch-and-release ethics for each species is a conservation strategy and these contests have

been shown to be effective in raising awareness of species conservation and getting people's attention (Cooke and Suski 2005). The catch data of mahseer (*Tor* spp.) from the Cauvery River in India is a good example of how organised angling can be used as a tool to monitor species conservation, as it effectively contributes to species conservation and fisheries management measures (Pinder et al. 2015). The appreciation of environmental goods and services is often a part of societal culture and digitised or documented information, such as angler logbooks, helps to understand the behaviour of recreational anglers towards a species (Hutt et al. 2013) and can be used for conservation and management measures via culturomics. Angler's ecological knowledge, which largely depends on the size and frequency of their catches (van den Heuvel and Rönnbäck 2023), can be an effective tool for conservation alongside the cultural influences on their interpretations of environmental change (Thornton and Scheer 2012). There are approximately 226 million recreational anglers worldwide (World Bank 2002; Arlinghaus et al. 2015, 2019) and ~ 3% of the total population of Czechia are registered in angling unions (Boukal et al. 2012), so this angling information, if systematically retrieved and analysed, can provide a good source of information for conservation efforts.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

This study did not involve handling of animals or personal information.

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Author contributions

Marek Šmejkal: Conceptualisation, Investigation, Data curation, Formal analysis, Writing Original draft, Writing, Review & Editing, Visualisation. Kiran Thomas: Formal analysis, Visualisation, Writing, Review & Editing. Vladimír Kořen: Conceptualisation, Writing, Review & Editing. Jan Kubečka: Conceptualisation, Data curation, Writing, Review & Editing.

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Data availability

Data will be shared by authors upon reasonable request.

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Supplementary material 1

Individual data points

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